Boeing North American, Inc.
Reusable Space Systems

FLORIDA OPERATIONS
NASA SHUTTLE LOGISTICS DEPOT
MATERIALS AND PROCESSES
TEST REPORT

FA No: 00-087
Sub-CAR: KB4157-014
PRR: 95904M
NR: N/A

DATE RECEIVED IN LAB: 11/00

NOMENCLATURE/SUBJECT: **Evaluation of Bulkhead Penetration Line, P/N MC271-0085-1016, S/N 52054000004**

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ABSTRACT

During leak test operations an audible leak was detected in the hose. The flex hose was subsequently removed and routed to scrap. A Sub-Car was then issued to retrieve the hose from scrap and route it to M&P to determine the cause of the failure.

The leakage failure of the flex hose was due to a ruptured convolute in the bellows which was caused by fatigue due to cyclical flexing of the hose during operation. The failure occurred at the end of the hose which is allowed three axes of movement. The hose was also an original hose installed in OV-104, and was in service for 20 missions. The fact that the hose was subjected to cyclical loading over a prolonged period of time increases the probability of this type of failure.

INTRODUCTION

During leak test operations an audible leak was detected in the hose. The flex hose was subsequently removed and routed to scrap. A Sub-Car was then issued to retrieve the hose from scrap and route it to M&P to determine the cause of the failure if possible.

PROCEDURE

Nondestructive Testing

The hose was received marked with a piece of tape indicating the leak occurred in the end of the hose which was mounted to the payload bay floor, see Figure 1. The other end of the hose is

mounted to the Xo 582 bulkhead. The hose was x-rayed to locate the leak so the hose could be sectioned for analysis. Three different views were taken approximately 0, 120 and 240 degrees but no leak path was evident.

The hose was then was then leak tested using GN2. At 5 psi a blowing leak was detected under the fitting on the end of the hose, as seen in Figure 1, and Figure 2. The initial radiography did not evaluate the area under the fitting. Radiography was again performed concentrating on the leaking area of the hose and a fractured convolute was evident in one view. The failure occurred in the valley of the first convolute after the weld joint which attaches the tube and bellows.

Dissection/Visual Inspection

The metal braiding was cut away to expose the failed end of the bellows. Using a Dremel tool the fitting which holds the braiding over the bellows was removed to obtain complete access to the failed convolute.

The failed convolute was examined at 20 to 50X and revealed a rupture in the bellows approximately 60 degrees long. Figure 3 shows the location of the failure behind the weld joint as well as the rupture in the valley of the convolute. Further inspection revealed a hairline crack which did not penetrate the base metal that extended approximately another 210 degrees, see Figure 4. The crack also followed what appeared to be a forming mark in the valley of the convolute. A detailed photograph of the forming mark could not be obtained on the optical microscope due to part size, geometry and lighting effects.

Scanning Electron Microscopy (SEM) and Energy Dispersive X-Ray Spectroscopy (EDS)

The fractured convolute was mounted for analysis of the fracture surface utilizing the JEOL 5800 LV SEM. A representative photograph of the forming mark along which cracking occurred is shown in Figure 5. Examination of the fracture surface in the ruptured convolute exhibited fatigue striations, refer to Figure 6.

The failed bellows was taken to the NASA MAB Lab at KSC for a second opinion. In order to get a better look at the striations, ID as well as OD, it was decided to pull the surfaces apart. This was accomplished by sawing about a third of the way through the bellows about 180 degrees from the ruptured area. Sufficient force was applied until the bellows was pulled apart. The exposed surfaces were again mounted for SEM examination.

The fatigue striations in the ruptured area as well as multiple origins were evident. The striations appeared to initiate from the OD. Further evaluation revealed areas where it appeared the striations originated from the ID as well as the OD, refer to Figure 7.

Qualitative chemical analysis was performed utilizing the JEOL 5800 LV SEM and Kevex Super Dry energy dispersive x-ray spectrometer. SEM/EDS analysis showed no corrosion products on the fracture surfaces. Qualitative chemical analysis indicated the bellows was 321stainless steel as a spectrum of Fe, Cr, Ni and Ti were obtained, see EDS plot in Figure 8.

Metallography

A transverse section of the bellows was removed and mounted for metallographic examination to inspect the inner and outer surfaces. The sample was polished and etched using methanolic aqua regia to reveal the microstructure. The microstructure was typical of an austenitic stainless steel and can be seen in Figure 9. The specimen also revealed cracking adjacent to the fracture surface on the OD and ID, see Figure 9.

RESULTS and DISCUSSION

The leakage failure of the flex hose was due to fatigue as evidenced by the fatigue striations which propagated through the bellows convolute on the inner and outer diameters until failure occurred, see Figures 6 and 7. The end of the hose which failed is configured in such a way that it is allowed to flex in three axes. The failed hose was also subjected to many cycles as it is an original hose installed on OV-104 and has been in service for 20 missions. The hose is also subjected to pneumatic, vibration and temperature cycling during operation which could have also contributed to the failure.

The failure appeared to have initiated by surface cracking which resulted from the cyclical bending applied to the hose. The crack on the outer convolute followed a forming mark which acted as stress concentration point. The cyclical bending caused stress concentrations on the inner and outer surfaces of the failed convolute, which caused small cracks to form on these surfaces as seen in the metallographic inspection Figure 9. Eventually, multiple cracks were formed, each serving as an origin for the propagation of the fatigue striations which resulted from the flexural cycling.

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CONCLUSIONS

The leakage failure of the flexhose was due to a ruptured convolute in the bellows which was caused by fatigue due to cyclical flexing of the hose during operation. The failure occurred at the end of the hose which is allowed three axes of movement. The hose was also an original hose installed in OV-104, and was in service for 20 missions. The fact that the hose was subjected to cyclical loading over a prolonged period of time increases the probability of this type of failure.

CONTRIBUTORS

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Peer Review: _____

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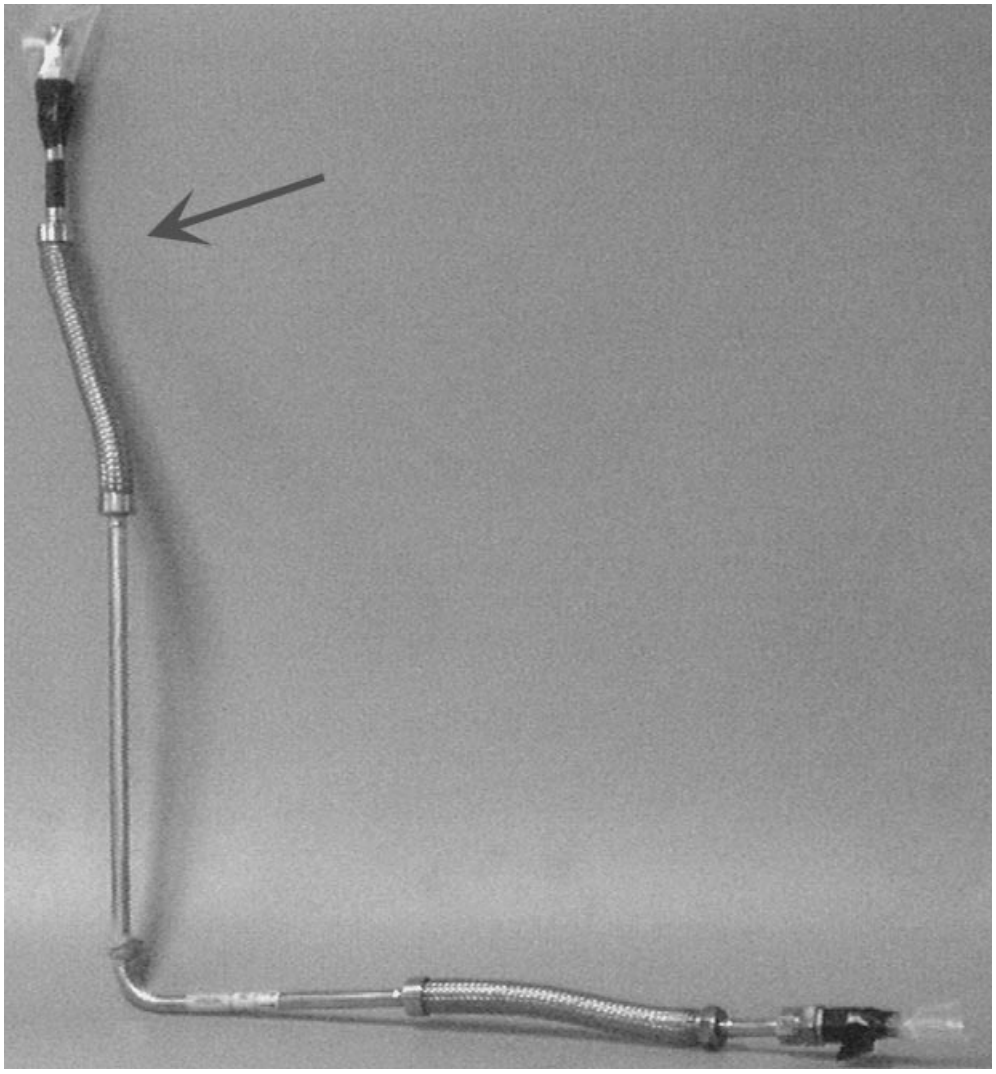

Figure 1: Overall view of flex hose. Arrow indicates area where leakage was detected.

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Figure 2: Closeup of Figure 1. Arrow indicates leakage from ruptured bellows convolute located under fitting.

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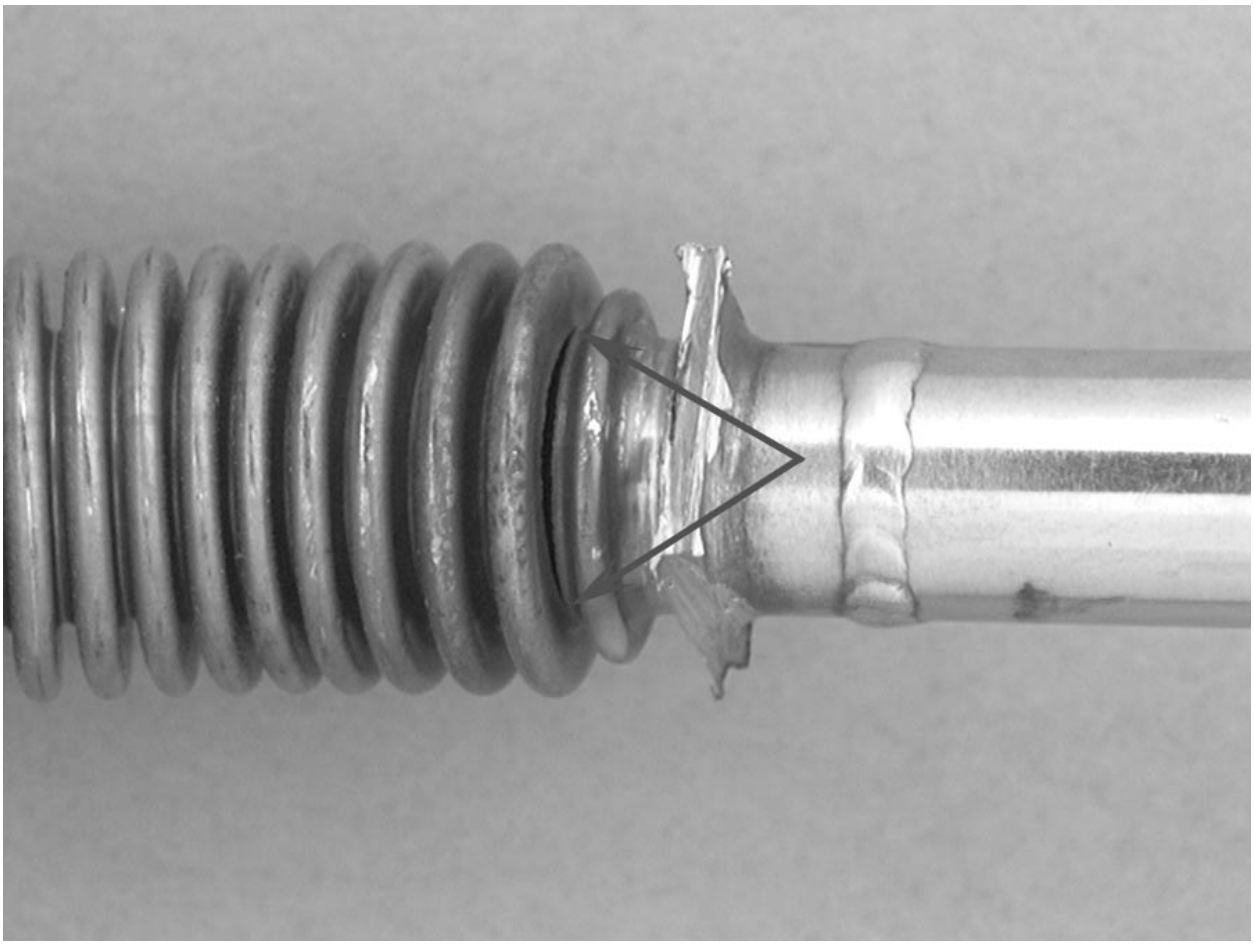

Figure 3: Ruptured convolute in valley of bellows

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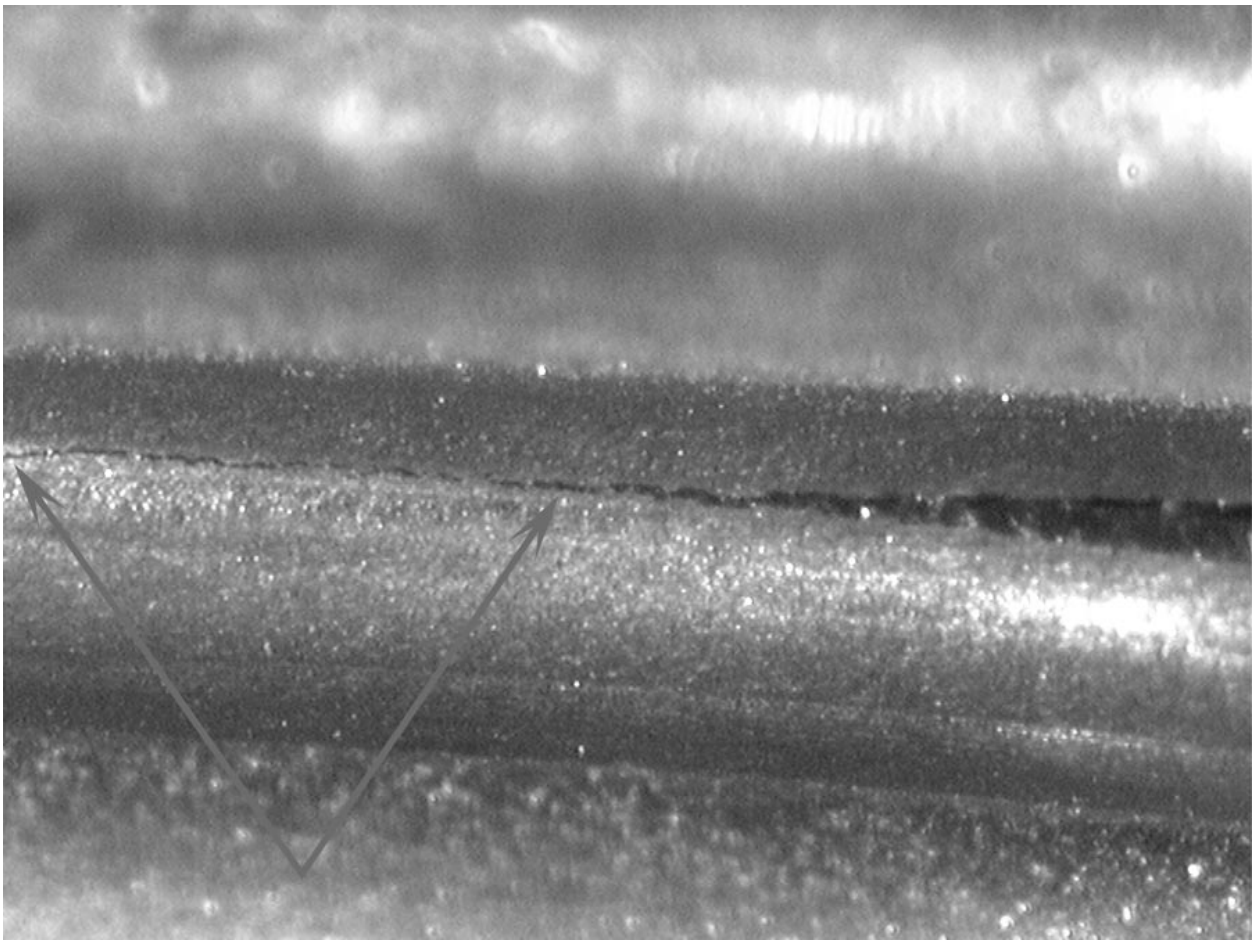

Figure 4: Hairline crack which continued from ruptured surface for an additional 210 degrees.

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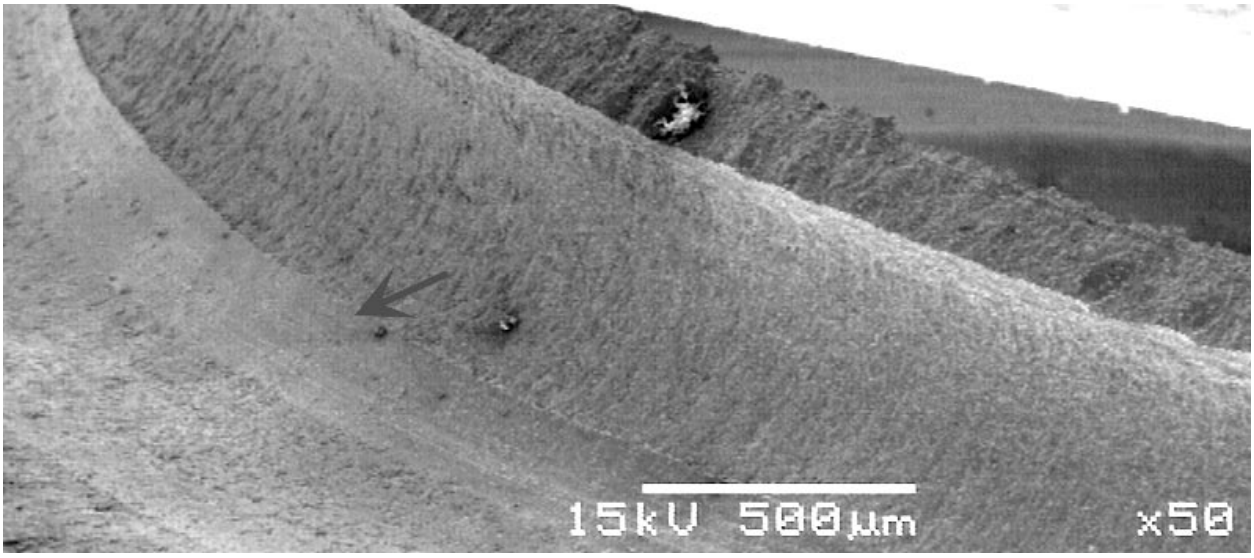

Figure 5: Arrow indicates forming mark along which crack propagated.

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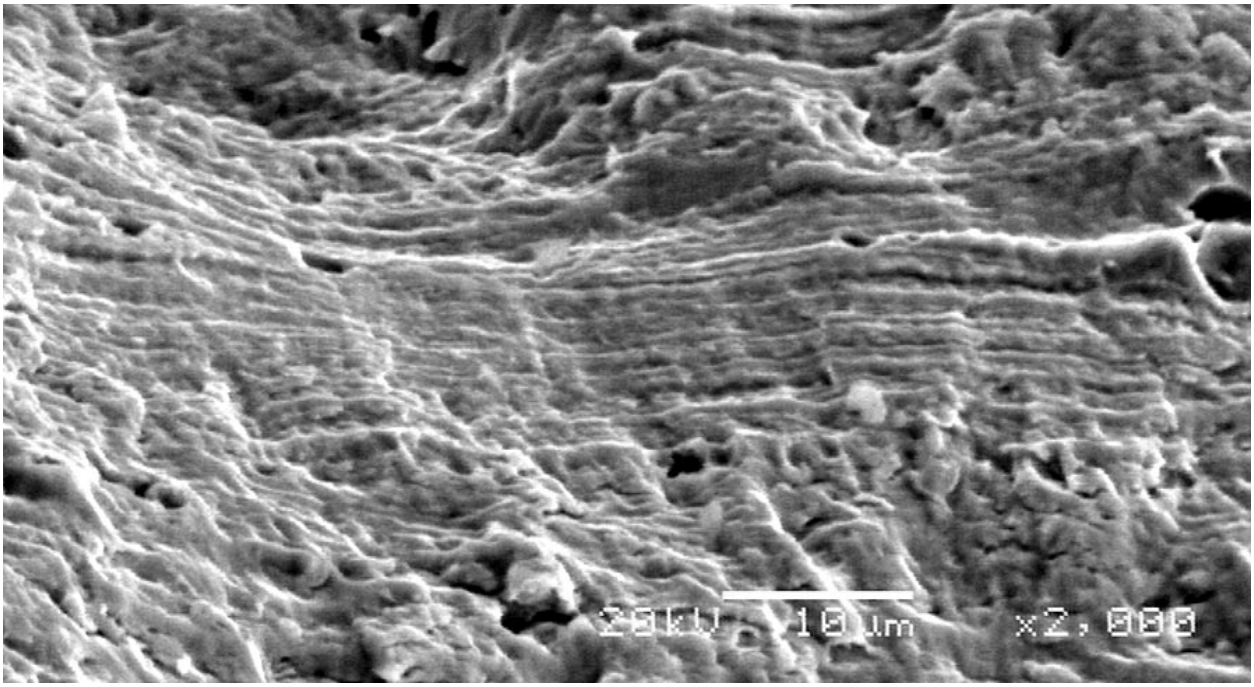

Figure 6: Fatigue striations on the outer diameter of the failed convolute.

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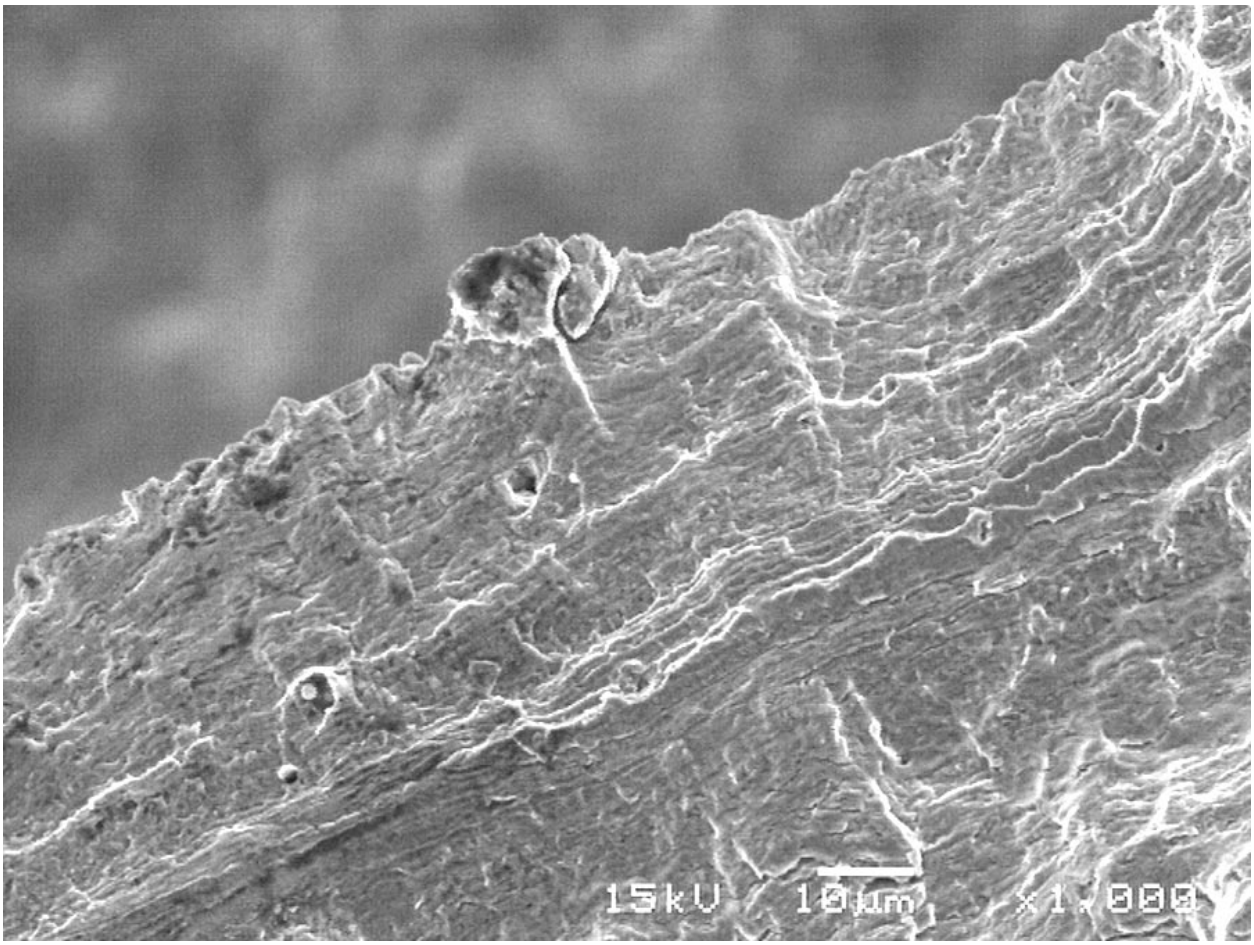

Figure 7: Fatigue striations on the inner diameter of the failed convolute.

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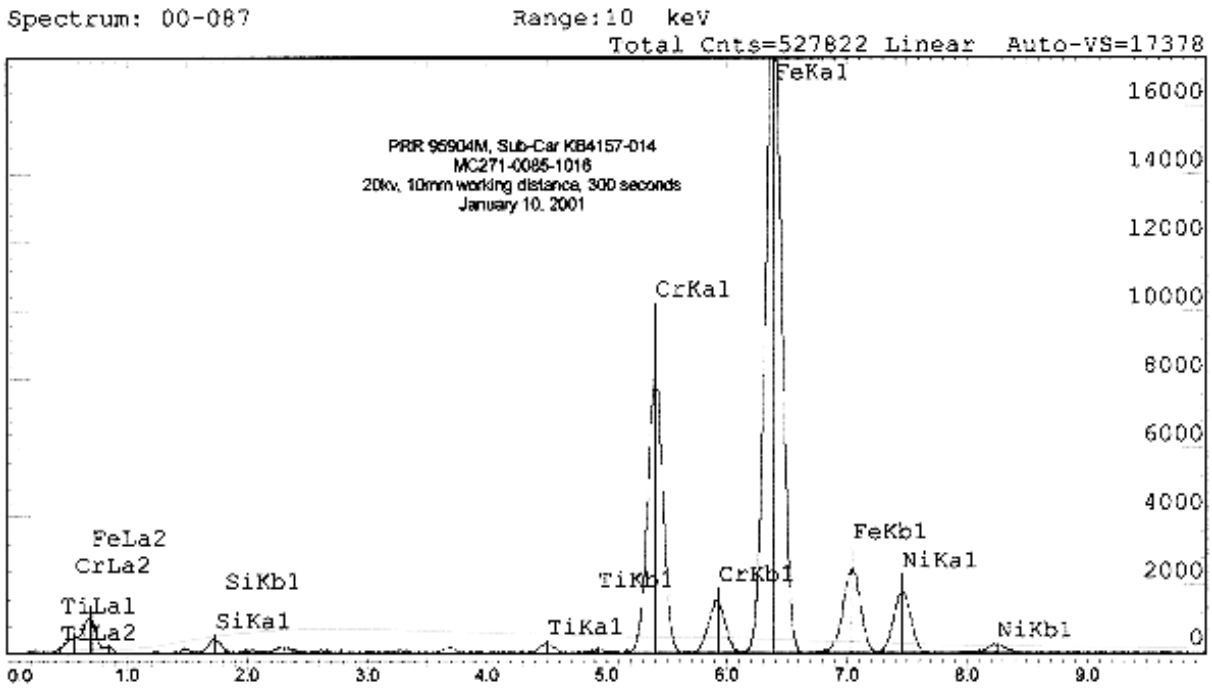

Figure 8: EDS plot of bellows material.

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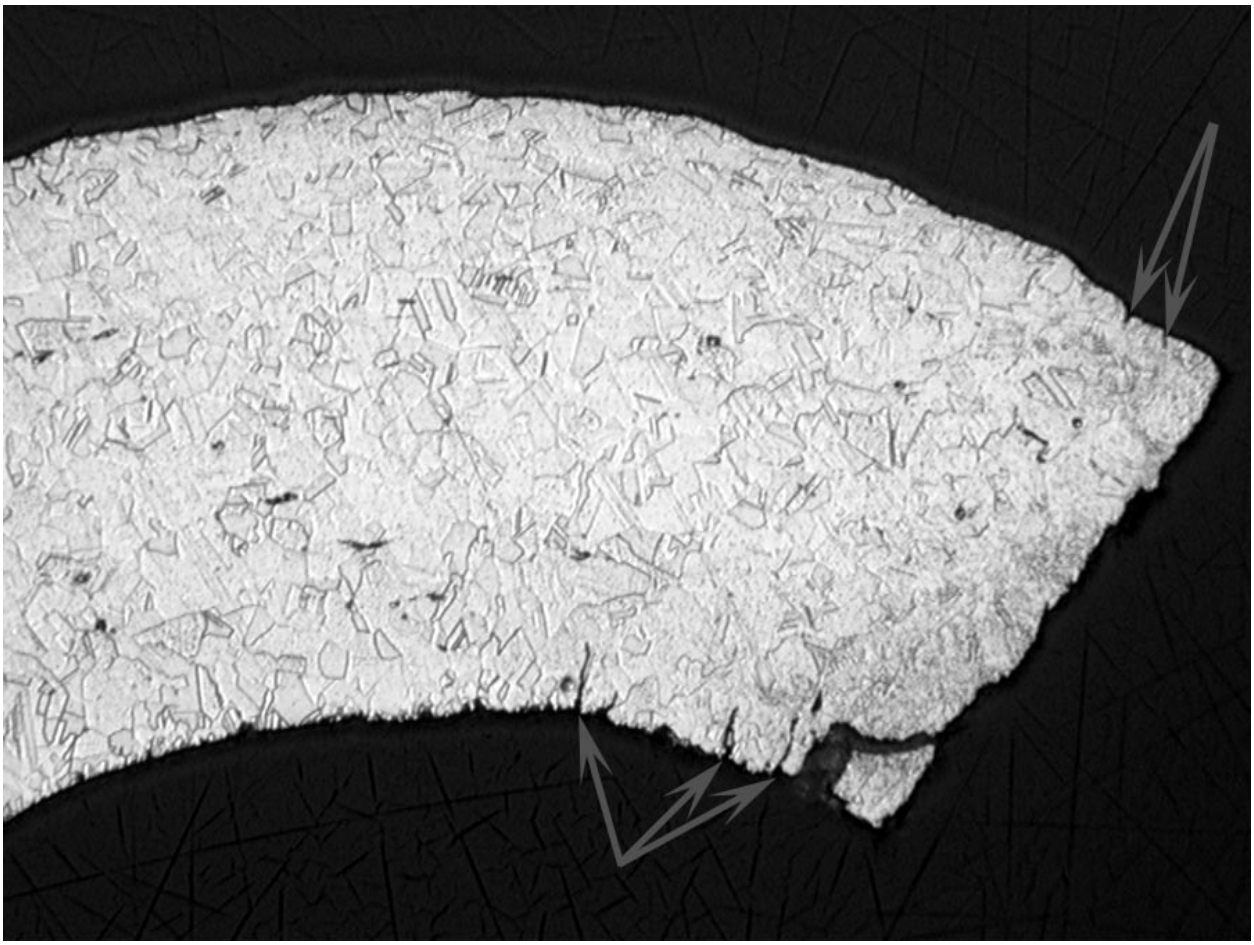

Figure 9: Photomicrograph of failed convolute. Arrows indicate cracking on outer and inner diameters.

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